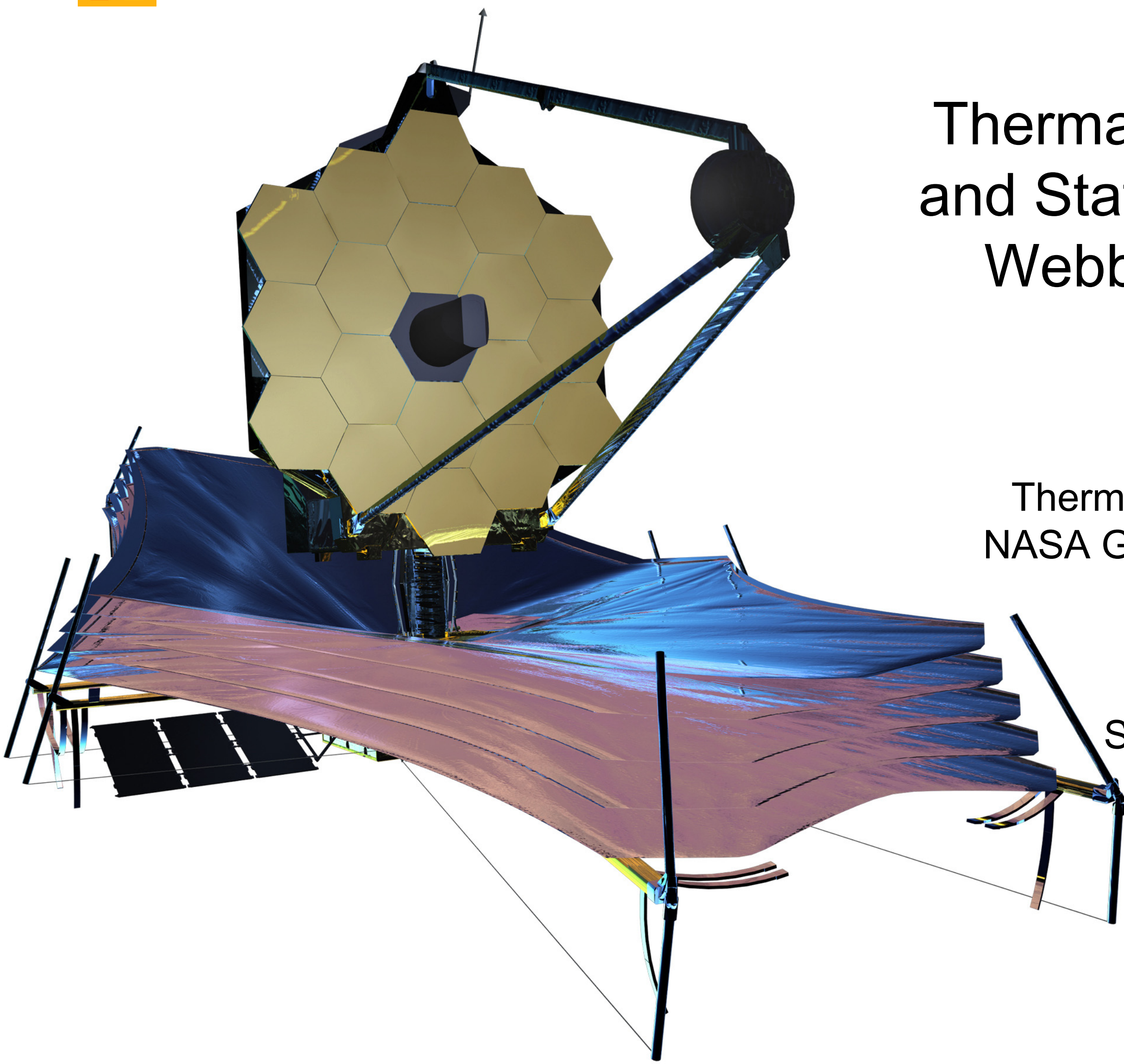
NORTHROP GRUMMAN Space Technology

JWST Thermal Systems

Thermal Design Challenges and Status of NASA's James Webb Space Telescope



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Acknowledgments

Shaun Thomson (NASA)
John Pohner (NGST)

From Spitzer to Herschel and Beyond: The Future of Far-Infrared Space Astrophysics Conference
June 7, 2004

JWST Mission Overview

JWST Observatory Overview

JWST Thermal Architecture and Requirements

Sunshield

Integrated Science Instrument Module (ISIM)

Thermal Design Challenges

ISIM Warm Electronic Accomodation
Cool-Down Control/Contamination
Sunshield/Bus Closeout

design

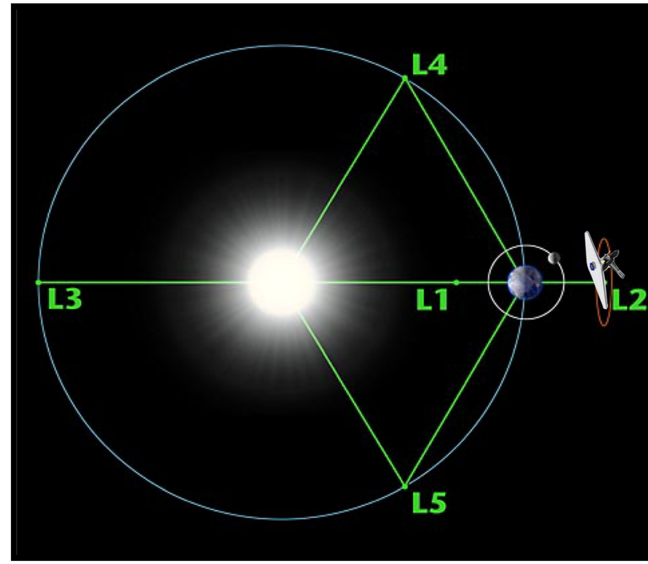
Verification and Modeling

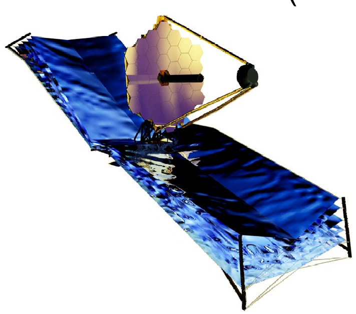
philosophy

James Webb Space Telescope
Cryogenic Infrared Observatory at a Glance

- Mission Objective
  - Detailed study of the birth and evolution galaxies
  - Optimized for near infrared wavelength (0.6 –28 μm)

- Organization
  - Mission Lead: Goddard Space Flight Center
  - International collaboration with ESA & CSA
  - Prime Contractor: Northrop Grumman Space Technology
  - Instruments:
    - Near Infrared Camera (NIRCam) – Univ. of Arizona
    - Near Infrared Spectrometer (NIRSpec) – ESA
    - Mid-Infrared Instrument (MIRI) – JPL/ESA
    - Fine Guidance Sensor (FGS) – CSA



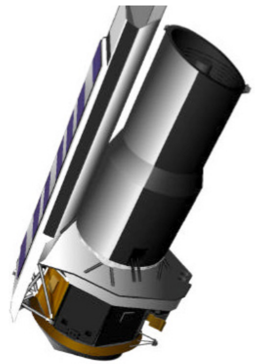


- Description
  - Approx. 6 m diameter deployable, active optics, primary mirror
  - Launched by Ariane 5(TBR) from Kourou, French Guiana, direct insertion to L2 orbit
  - Integrated Science Instrument Model (ISIM) consisting of 3 science instruments and a guider
- Website
  - www.JWST.nasa.gov

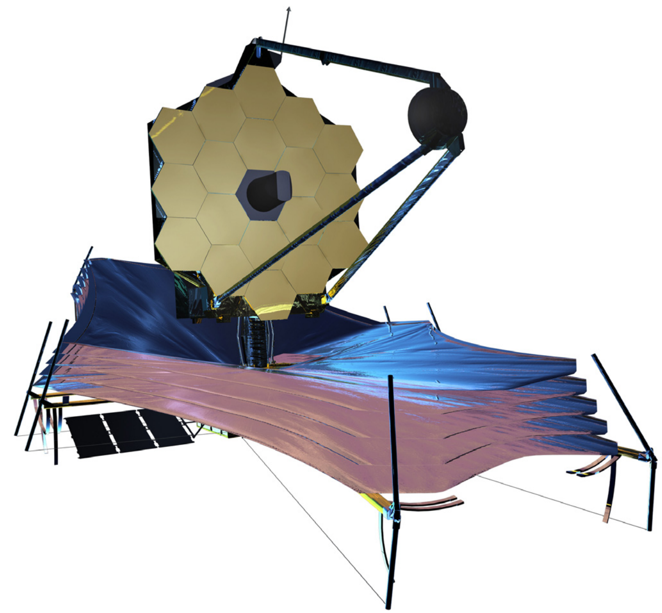
FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11
Formulation Phase (A/B)							Implementation Phase (C/D)					
				Select Prime	SRR	NAR	PDR	CDR		MOR		Launch Timeframe

JWST builds on achievements of SST/HST

Spitzer Space Telescope



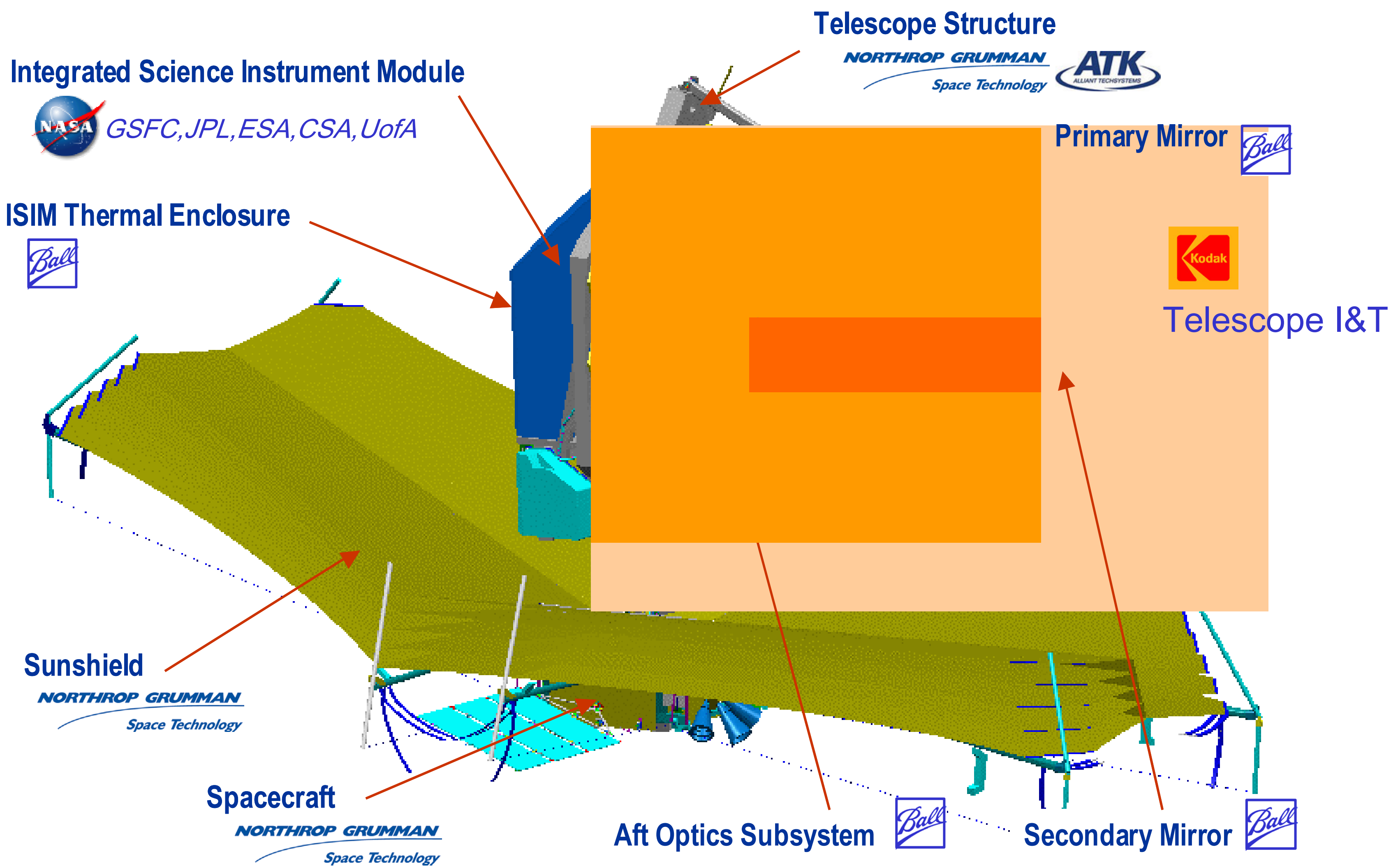
Hubble Space Telescope



JWST

- Collecting area
- Angular resolution
- Low background

JWST – Observatory Overview



Launch Vehicle Challenges

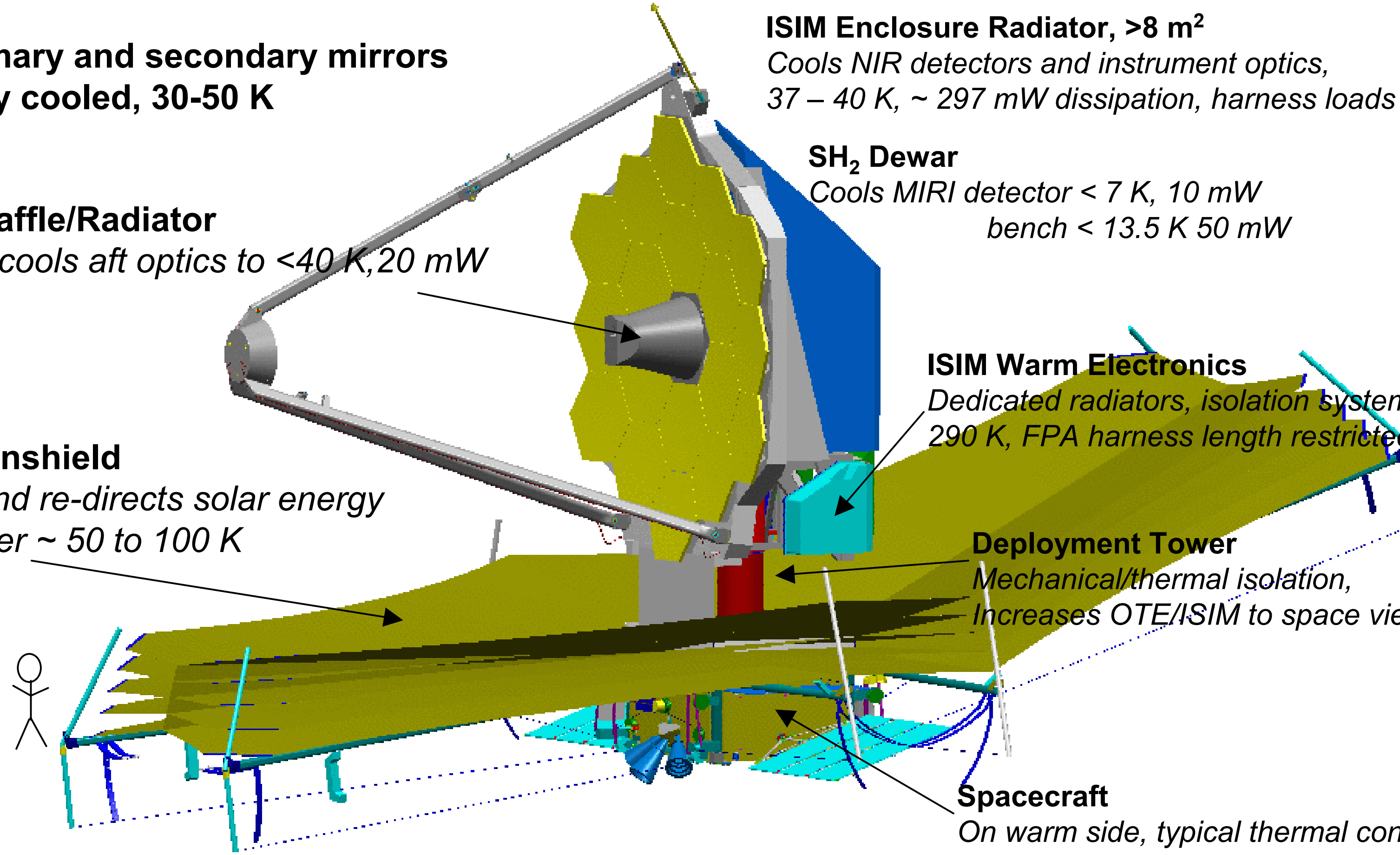
- Launch vehicle is Ariane 5(TBR)
- Must maintain compatibility with US EELV Heavy
- Even on these vehicles JWST is extremely mass challenged
  - 6000-7000 kg
  - Mirror fabrication has begun. Mass of telescope is soon non-negotiable
- Servicing of SH_2 Dewar at launch site and on-vehicle at pad
- Potential solar illumination of mirrors and large radiators during launch phase.

Thermal Architecture Overview

OTE primary and secondary mirrors passively cooled, 30-50 K

Central Baffle/Radiator
Passively cools aft optics to <40 K,20 mW

5 – Layer Sunshield
Attenuates and re-directs solar energy
Cold side layer ~ 50 to 100 K



ISIM Enclosure Radiator, >8 m^2
Cools NIR detectors and instrument optics,
37 – 40 K, ~ 297 mW dissipation, harness loads

SH$_2$ Dewar
Cools MIRI detector < 7 K, 10 mW
bench < 13.5 K 50 mW

ISIM Warm Electronics
Dedicated radiators, isolation system
290 K, FPA harness length restricted

Deployment Tower
Mechanical/thermal isolation,
Increases OTE/ISIM to space view

Spacecraft
On warm side, typical thermal control,
20-40 C

JWST is configured to be a passive multi-stage cryogenic radiator system

System/Thermal Requirements Inter-Relationships

MR-51 Sensitivity

MR-122 **Stray Light From Thermal Emissions**

Thermal emissions from the Observatory that reach the final OTE focal plane shall contribute less flux than that from an equivalent on-axis astronomical source whose brightness is 3.9 MJy/sr and 200 MJy/sr, at 10 μm and 20 μm respectively.

MR-211 **Optical Transmission**

Accounting for all effects on mirror transmission including: coatings, dust obscuration, meteoroid damage, and contamination, the End of Life (EOL) optical spectral transmission of the OTE shall be greater than the values shown in the following table for wavelengths between 0.6 μm and 2.0 μm, and greater than 88% for wavelengths from 2.0 μm to 27 μm.

Sensitivity Verification

modeling

System Thermal Models

- Sunshield, OTE, ISIM, Instrument steady state temperature profiles
- Cool down profiles
- Thermo-optical properties
- Thermal model geometry

Stray-light Analyses
Contamination Analyses

allocations

Specification Inputs
*heater control and design
*sunshield attenuation performance
*coatings

Thermal Requirements
- Baffle/shielding/coatings
- Optics temperatures
- Cool-down and gradient control

System/Thermal Requirements Inter-Relationships

Image Quality

MR-113 **Encircled Energy 24 Hour Stability**

Without requiring ground-commanded correction, there shall be less than 2 percent root-mean-squared (RMS) variation about the mean encircled energy, defined to be at 0.15 arc-second radius at a wavelength of 1μm, over a 24 hour period.

MR-114 **Conditions**

The 24 hour stability requirements shall be met for any combination of target pointings within the field of regard (FOR), including those separated by a slew with a thermally worst-case 10 degree pitch change.

MR-178 **Re-Pointing**

Re-pointing time for any slew less than or equal to 90 degrees shall be less than 60 minutes, which includes mechanical and thermal settling, and guide star acquisition.

Image Quality Verification

modeling

System Thermal Models

- OTE Temperature Stability
- ISIM/Instrument Temperature Stability
- Bulk Average Steady State Temps

Dimensional Stability/Optical Analyses

allocations

IRD/ICD Inputs
*Power Stability
*Interface Stability

Specification Inputs
*heater control and design
*sunshield attenuation performance
*composite lay-up zero CTE temp

Thermal Requirements
- Temperature Stabilities
- Bulk Average Temperatures
- Cool-down and gradient control

Thermal Specific Requirements - Passive Cooling of NIR Detectors

MR-271 **NIR IR Detector Cooling**

The Observatory shall passively cool the NIR Science Detectors to a temperature of 37K beginning at a time during commissioning that supports NIRCam and NIRSpec commissioning and continuing until the end of the science mission lifetime.

MR-270 **Architecture**

The observatory architecture shall allow for the passive cooling of ISIM-related components and electronics to their safe and operational limits

Allocation

OBS-176 **Near Infrared Detector Cooling**

The Observatory shall passively cool the NIR Detectors to a temperature of 37 K beginning at a time during commissioning that supports NIRCam and NIRSpec commissioning and continuing until the end of the science mission lifetime.

Rationale

- Passive cooling is mission enabling.
- Passive cooling requires complete architecture solution.
- 37 K based on HgCdTe detector performance. HgCdTe technology selected over colder 30 K InSb
- 37 K is a well defined hard limit. Observatory thermal architecture is driven by this requirement.
- This requirement flows down in some aspect to all observatory, element, and subsystem IRDs and specifications.

Flow-down Example

Spacecraft
SCE (OBS-1610) **Solar Shielding**
The Spacecraft shall shield the ISIM to allow for the passive cooling of the near infrared (NIR) detectors following the commissioning of the science instruments (SIs).

ISIM
ISIM Requirement Document

→ ISIM thermal subsystem heat transport requirements

OTE
ISIM to OTE and Spacecraft IRD
JWST-IRD-000640
D36129

→ ISIM enclosure radiator requirements

Thermal Specific Requirements – Cryogenic Heat Rejection Capacity Margin

MR-91

The calculated margin on the heat rejection capacity of cryogenic systems shall be no less than 50% at the Critical Design Review (CDR). (This requirement does not apply to stored cryogen.) For all cryogenic components(<100 Kelvin), margin is defined as excess heat rejection capacity as a percentage of the calculated load. Calculated load includes power dissipation and predicted radiative and conductive parasitics. Heat rejection capacity is calculated at the maximum allowable operating temperature. Excess capacity is defined as the rejection capacity minus the calculated load

Rationale

- Cooling margin and temperature combine to drive overall architecture – radiator sizes, power allocation, related mass.
- Margin is held as reserve until design is solidified and thermal models account for all potential heat loads.
- Unique thermal nature of JWST requires judicious use of of objective and well-defined cryogenic design practices

Discussion/Example

$$\text{margin (\%)} = \frac{T_{required}^{4} - T_{predicted}^{4}}{T_{predicted}^{4}} 100$$

Modeling allocations

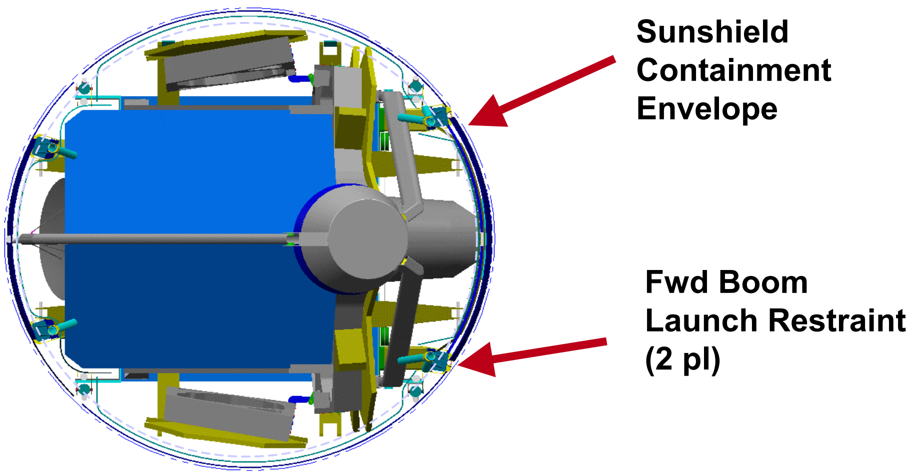
- power dissipation allocations
- parasitic allocations (loads based on harness models, etc.)
- worse case environment
- end-of-life thermo-optical properties, minimum radiator emittances
- maximum interface boundaries, temperature drops
- hottest attitude

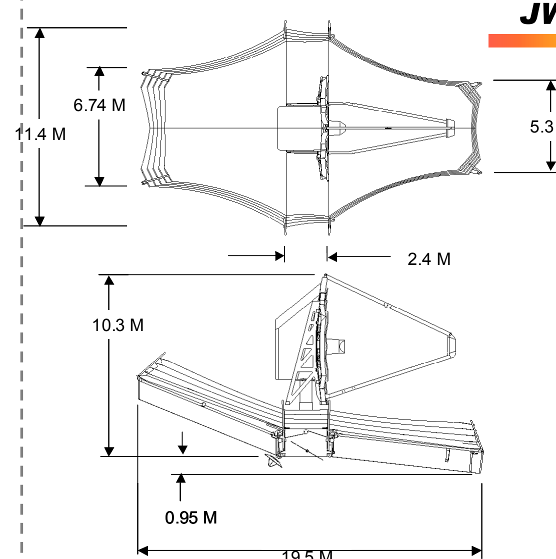
→ System Thermal Models → NIR detector temperature prediction

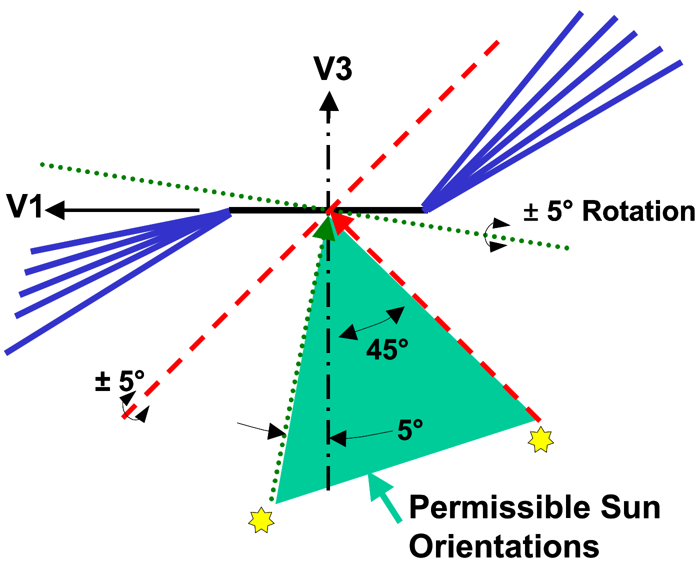
Prediction must be <32.1 K to meet 50% requirement

Sunshield Architecture

JWST Thermal Systems

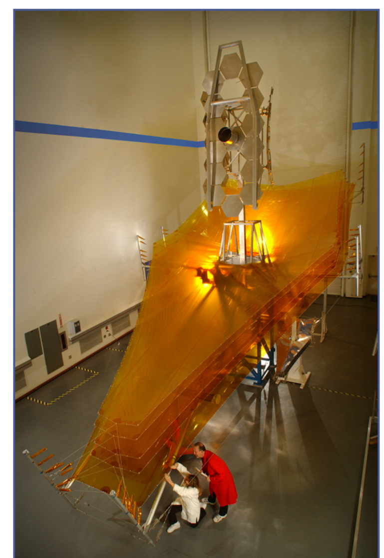




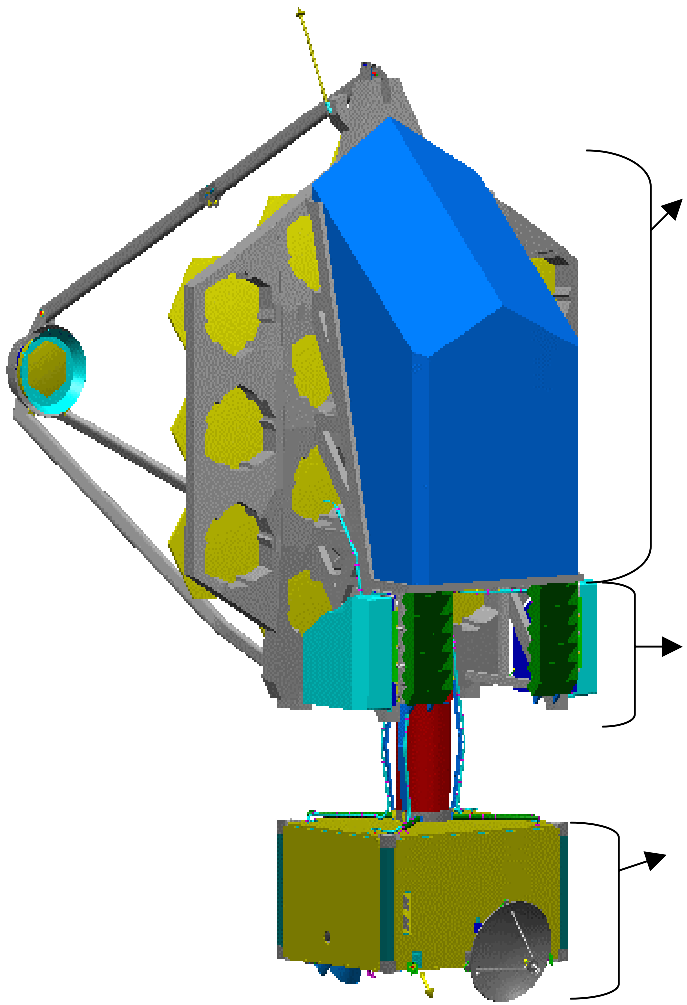


- Solar attenuation of 10^{-7}

- 5 layers of Kapton E with silicon and VDA coatings



ISIM Overview



What is ISIM?
- **The JWST Science Instruments**
- **Associated Infrastructure: Structure, C&DH, & FSW**

Region 1 (Cryogenic Region, 6K to 40 K)

Science Instrument Optics Assemblies

Near Infra-Red Camera (NIRCam)
Near Infra-Red Spectrometer (NIRSpec)
Mid Infra- Red Instrument (MIRI), & Dewar
Fine Guidance Sensor (FGS)
FGS Tunable Filter Instrument (FGS/TF)

Radiators and support structure (NGST supplied)

Region 2 (approximately 290 K)

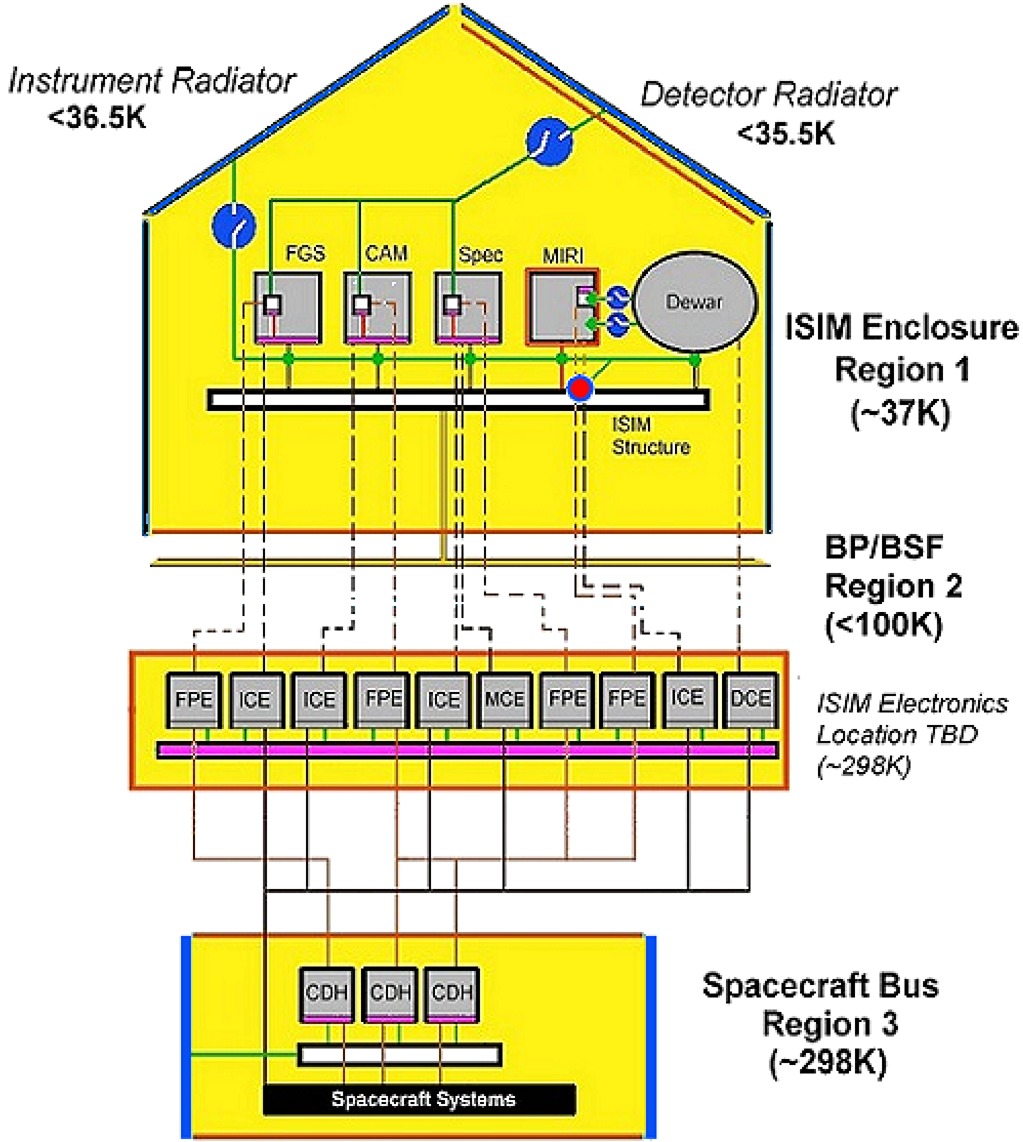
Focal Plane Electronics (FPE)
Instrument Control Electronics (ICE), MCE,DCE
Fine Steering Mirror (FSM) Differential Impedance Transducer (DIT)

Region 3

ISIM Command & Data Handling (C&DH) Electronics
FGS C&DH Electronics

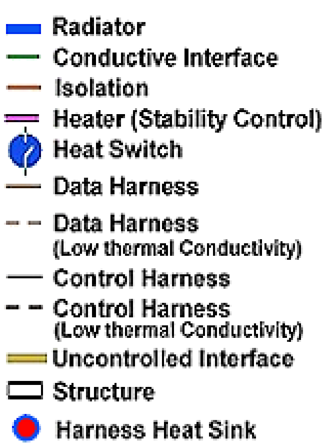
MCE- MEMS Control Electronics, DCE Dewer Control Electronics

Overall ISIM Thermal Control Network

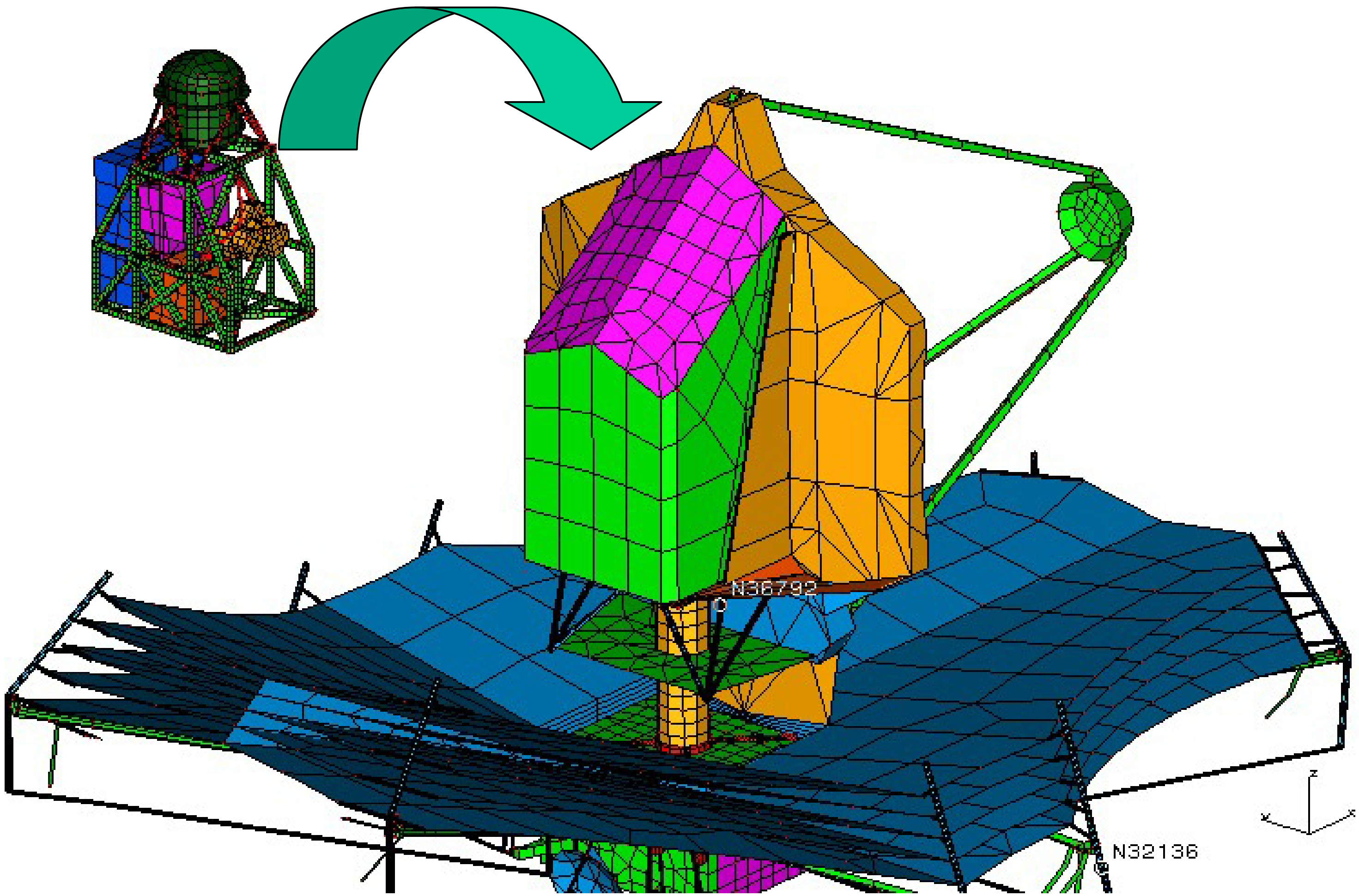


Basic Solution:

1. Establish passive heat sinks held below required temperatures (MIRI excepted)
2. Move dissipated heat efficiently from Instruments & Detectors to heat sinks
3. Limit introduction of Parasitic Heat
4. Maintain temperatures and rates of temperature change within acceptable limits throughout test & mission
5. Control power dissipation levels of detectors & instrument mechanisms

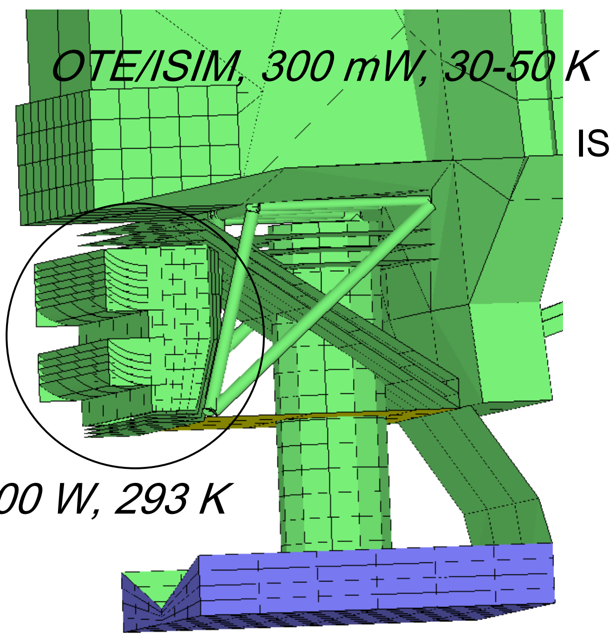


GSFC ISIM/Observatory TMG Thermal Model



Thermal Design Challenges – ISIM Warm Electronics

- ISIM detector electronics (290 K) need to be incompatibly close (<6m) to cryogenic (region 1) area.
- Extensive trade study now underway to optimize this critical thermal design area.
- Harness design critical (>3000 wires + shielding from warm electronics to Region 1
    - Harness materials and size chosen to minimize conduction/Joule heating over large temperature range



ISIM Electronics Compartment (IEC)

- *Soft mounted to and deploys with OTE/ISIM*
- *Launch locked/load carried to bus*
- *Specular baffles/radiator 'funnel' heat away from cold sunshield layer*
- *Muliple specular shields and parasitic guard radiators separate IEC from ISIM/Telescope*

Thermal Design Challenges – Cool-down Control/Contamination

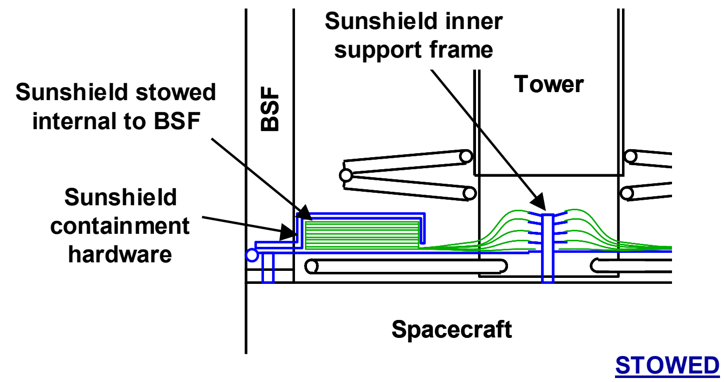
•Natural on-orbit cool-down is incompatible with contamination requirements and on-station steady state design

- optics and detectors naturally cool the quickest, drawing water from outgassing composite structures
- Mid-IR instrument is highly isolated to maximize cryogen lifetime. Does not want to cool-down
- On-orbit cool down period period (90-110 days) is not-practical for ground testing.
- Goal of 30 day test cool-down requires design features which are not compatible with low parasitic steady-state design.

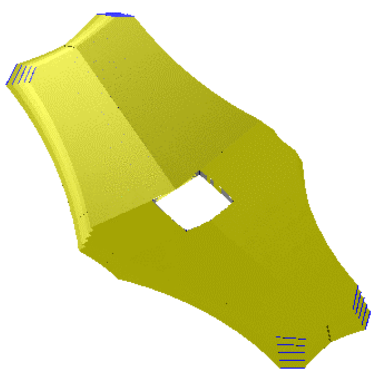
Heat Switches and Heaters

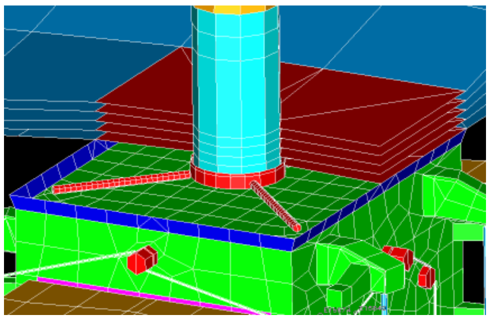
- Commandable heat switches "break" connection between components and radiators
    - Enables protection of detectors from possible overheating during pre-deployment.
    - MIRI heat switch (MIRI responsibility) connects instrument to dewar and keeps dewar isolated until ISIM environment and MIRI instrument temperature drops below 70K
        - Minimizes cryogen losses & extends MIRI lifetime
- Development underway

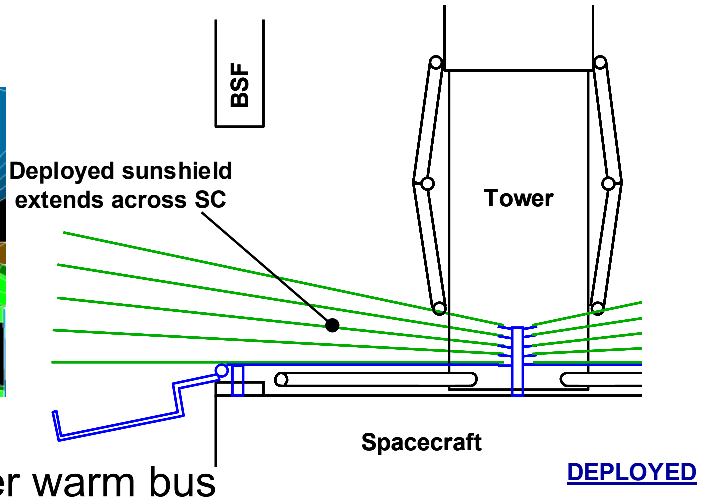
Thermal Design Challenges – Sunshield/Bus Closeout



Prior base-line has MLI only 'hole' across spacecraft bus







Sunshield needs effective closeout over warm bus
Design on-going to mechanically accommodate

Thermal Design Challenges – Verification and Modeling

JWST Thermal Modeling and Verification Realities

- large passive cryogenic system modeling in regime with very little flight heritage
- accurate model results are used in JWST design (mirror fabrication, optical stability, operations, instrument sensitivity, science goals and performance,etc.)
- large multi-national organization with a variety of modeling tools and practices
- difficult/ill-definable thermal interfaces
- piece-meal verification over several years, no flight configuration thermal balance

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Modeling Plan

JWST Thermal Systems

•Thermal modeling results are used extensively and uniquely to verify system level requirements and to develop and refine lower level requirements.

•Thermal modeling results are used extensively and uniquely to develop interface requirements and design specifications (e.g. OTE backplane composite lay-up, MIRI dewar interfaces)

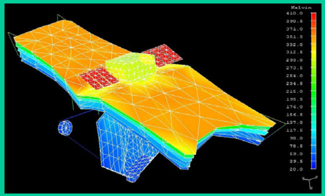
•Model validation is segmented and takes place over several years.

Modeling Plans and Quality Control

•Observatory performance will be assessed via two different independent modeling methodologies.

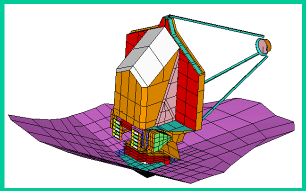
GSFC Observatory Modeling

- IDEAS/TMG (finite element modeler)
- ISIM Design and Instrument Analysis
- Observatory Performance



NGST Observatory Modeling

- TSS/SINDAG (NASA Standard finite difference)
- Observatory Design and Analysis (SC,OTE,SS)
- ISIM Performance



✓Quarterly model results and assumption audits
✓Performance metrics from both models compared and tracked
✓Common material and optical property databases
✓Independent, but common format, high level and detailed heat maps

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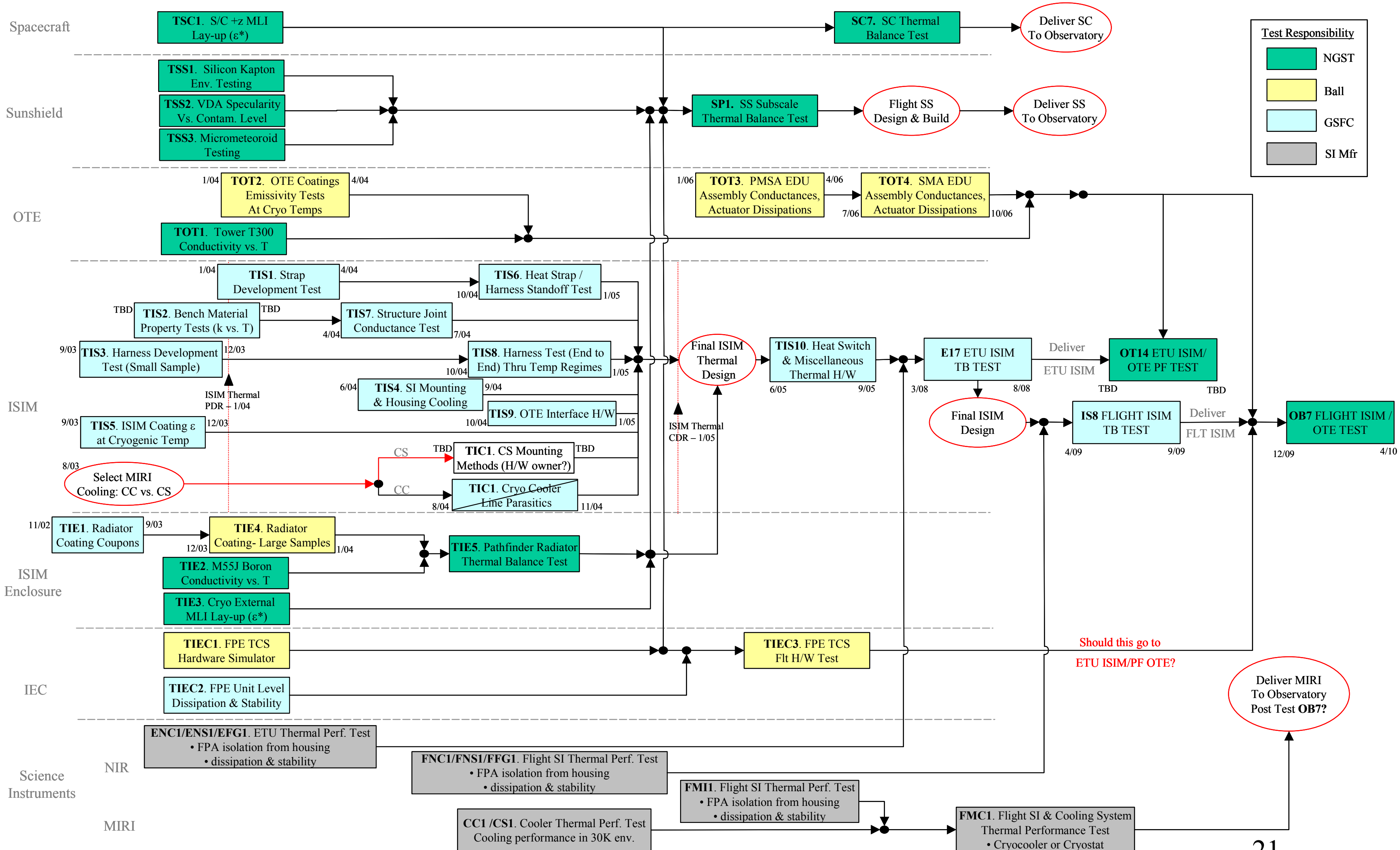
Thermal Verification Road Map – Visual Example

James Webb Space Telescope

JWST Thermal Systems

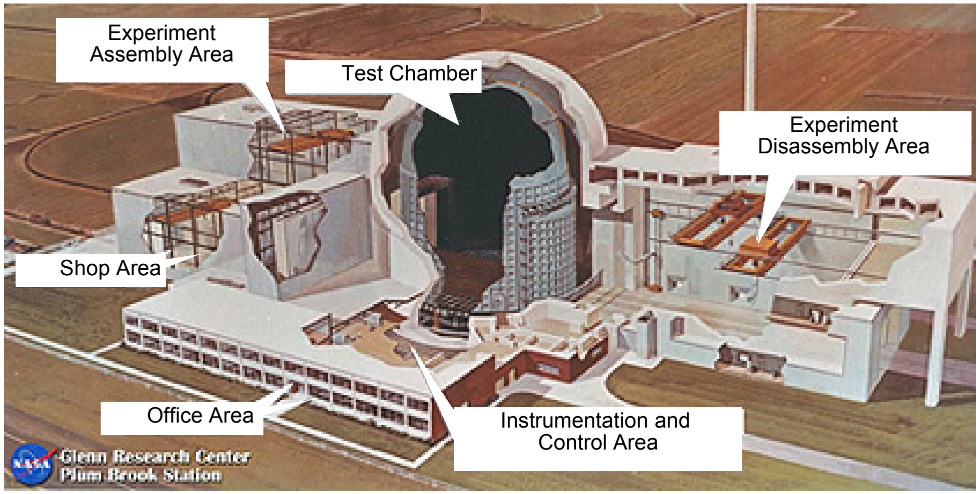


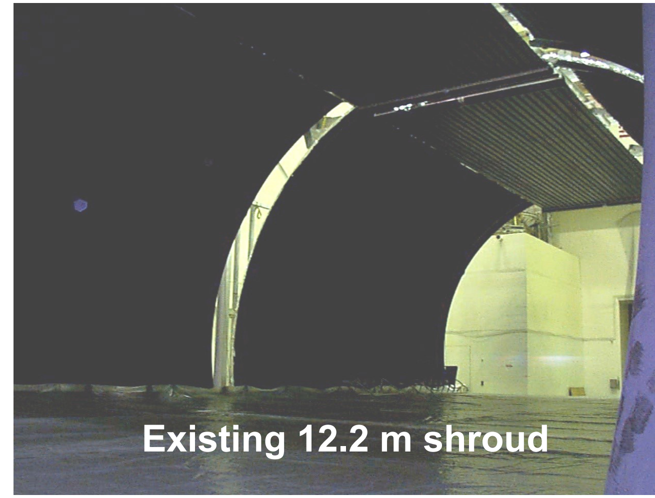
Verification Overview

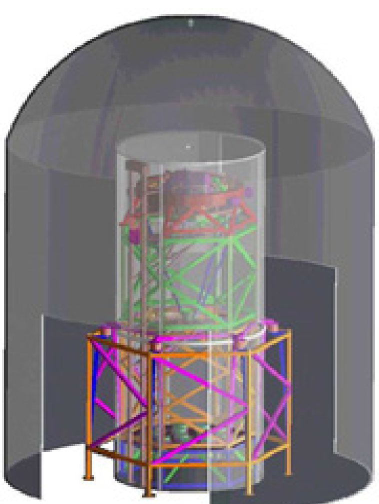
2004 **Developmental** – straps, heat switches, relays, harnessing, coatings, materials
Component – detectors, etc.
Radiator/Enclosure
½ Scale Hi-Fidelity Sunshield(with OTE/SIM SIM)
IEC
Instrument
ETU ISIM – *GSFC SES*
Flight ISIM
Telescope Pathfinder – *Glen Plumbrook Facility*
Telescope with ETU ISIM
Telescope with Flight ISIM
2011 Spacecraft Bus TB/TB

Confidence in predicted observatory performance must be achieved early in C/D

Plumbrook

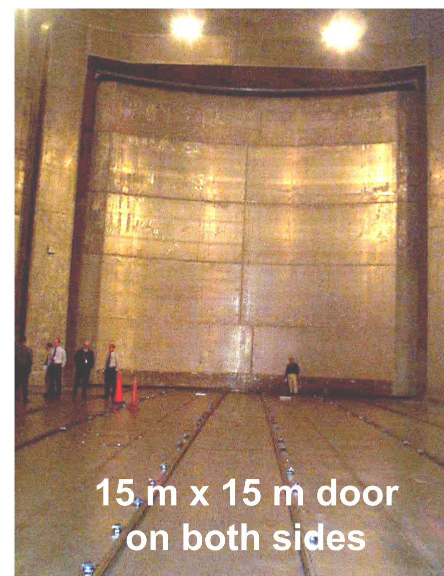


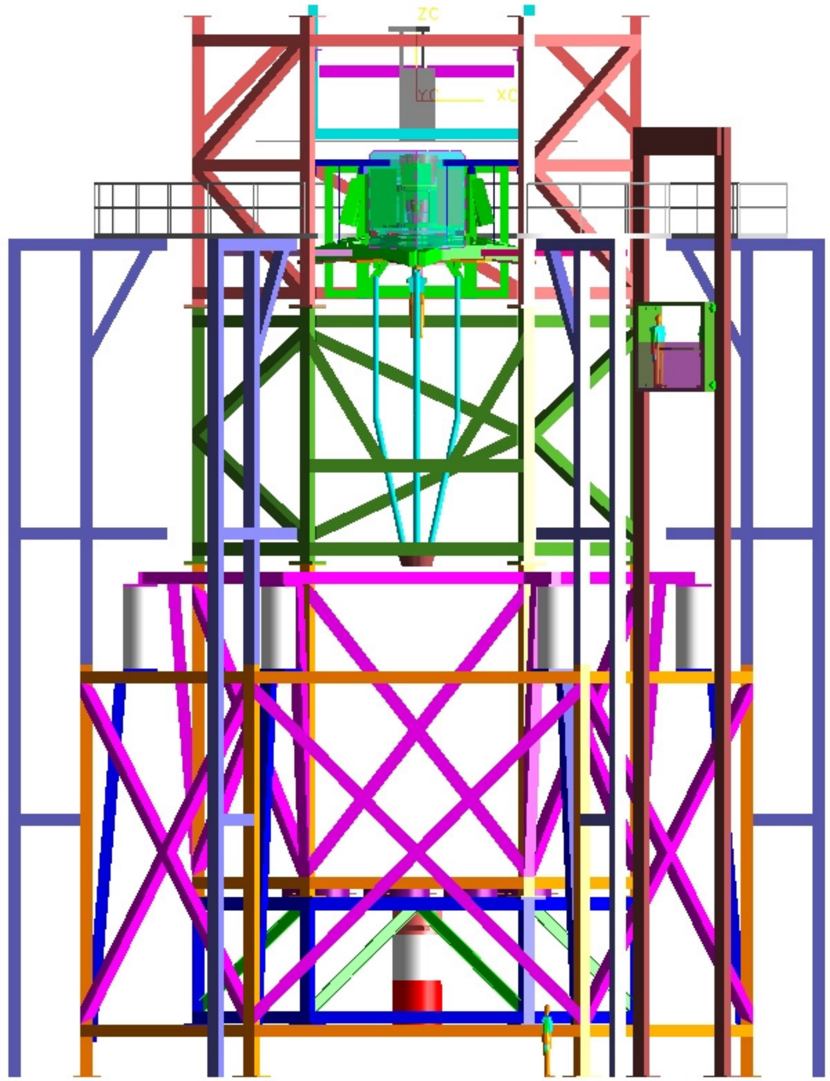




Plum Brook test facility provides the room to conduct a high fidelity thermal / vacuum environment in which the Observatory Optical performance is verified

OTE Pathfinder
OTE/ISIM Flight Article



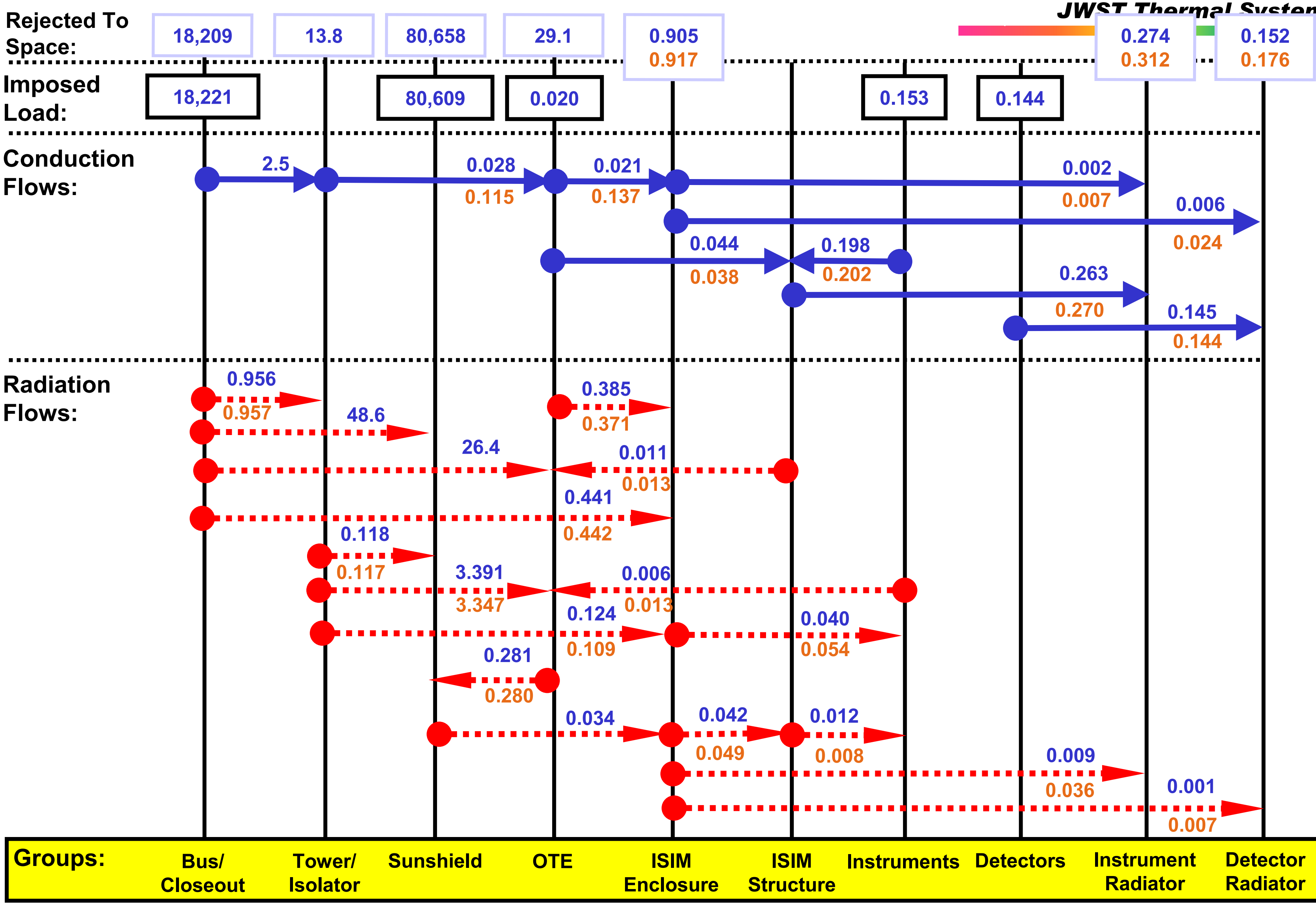

ZC
YC
XC

Observatory Top Level Heat Flow Map [W]

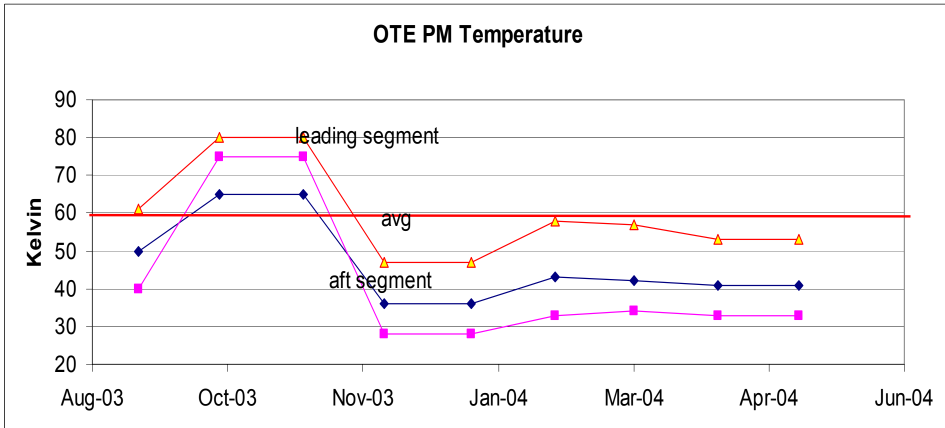
NGST/BATC Original: "Obs Truss v3.1" (+5°)

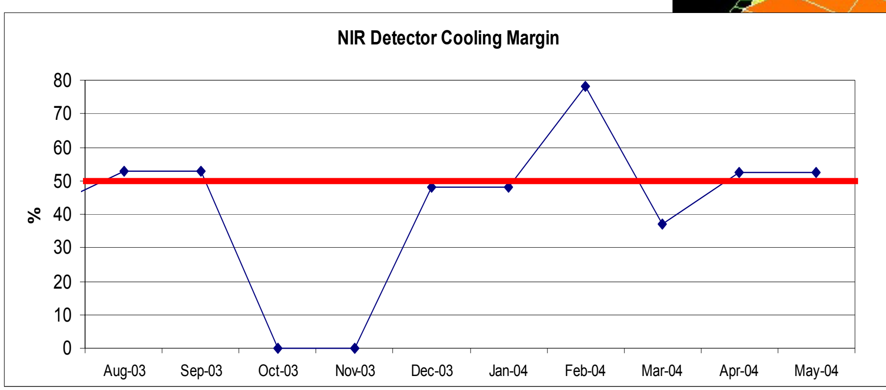
NGST/BATC Updated: "Obs Truss v3.1a corr" (+5°)

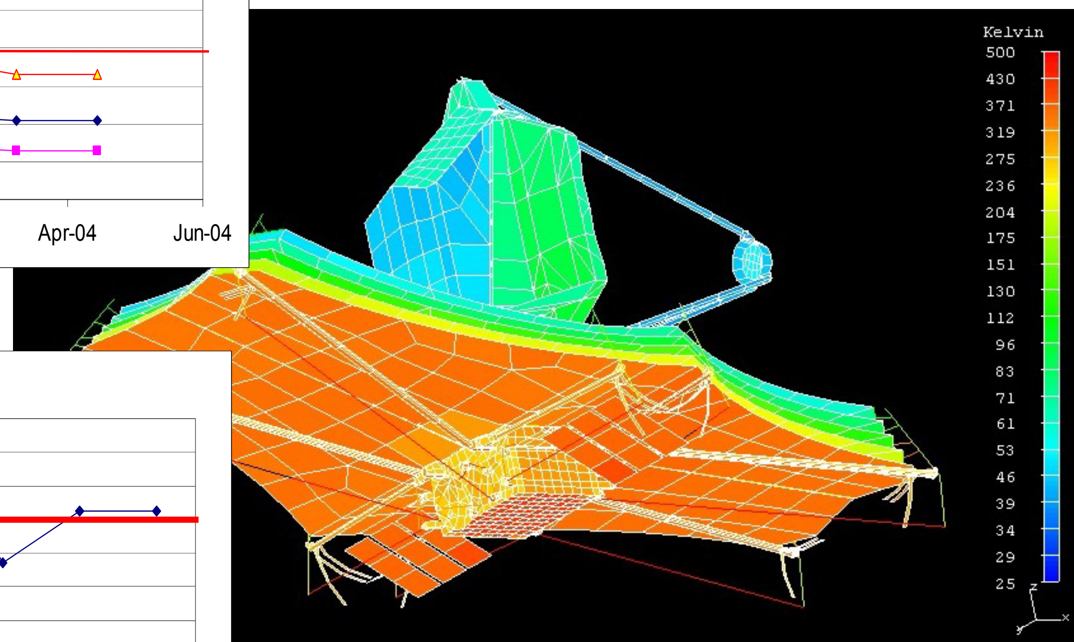
JWST Thermal Systems



Modeling Results







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